NOAA Technical Memorandum NOS NGS 38

VARIATION OF THE LINE OF SIGHT IN THE NI 002 LEVELING INSTRUMENT DUE TO TEMPERATURE CHANGE

Rockville, Md.
April 1983

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VARIATION OF THE LINE OF SIGHT IN THE NI 002 LEVELING INSTRUMENT DUE TO TEMPERATURE CHANGES

Heinz Poetzschke*
National Geodetic Survey
Charting & Geodetic Services, National Ocean Service
National Oceanic and Atmospheric Administration
Rockville, Md. 20852

ABSTRACT. The effect of temperature changes on the compensator, and consequently on the line of sight, of the Jenoptik NI 002 leveling instrument was investigated. The results of the experiment indicate that a change in temperature causes significant changes in individual collimation errors. But the change of the mean collimation error is insignificant because of the unique design of the instrument. Therefore, the effect of the change in collimation error on observed elevation differences is minimal, even without close balancing of backward and forward sight lengths.

INTRODUCTION

The NI 002 leveling instrument, manufactured by Jenoptik in Jena, German Democratic Republic, has become a mainstay in the leveling program of the National Geodetic Survey (NGS). This instrument was introduced at NGS in the mid-1970's. After initial testing, some 20 instruments were acquired for use in the releveling program for the new adjustment of the North American Vertical Datum. Two design features make the instrument more attractive than others. One is the swiveling eyepiece which eliminates the requirement for the observer to move around the instrument and tripod during observations. This not only saves time but reduces possible ground vibration which may affect the stability of the instrument. The other feature is the reversible compensator which consists of a plane-parallel mirror mounted in a pendulum device. The compensator unit is suspended by crossed invar ribbons on either side of the compensator. Because the compensator can be reversed, observations can be obtained in two compensator (mirror) positions, whose mean represents a quasi-absolute horizon.

However, there are occasions when difficulties arise in obtaining certain checks on the instrument's adjustment. The instrument is routinely taken through a procedure to determine collimation error, i.e., the deviation of the two-mirror positions relative to "true" horizontal. This represents the state of adjustment of the line of sight. Ideally, the two displacements should be of equal size with opposite signs, i.e., $C_1 = -C_2$, where C_1 and C_2 denote the collimation errors for compensator positions I and II, respectively. Also, either collimation error should not exceed a given upper limit. In the past, results obtained during field operations sometimes showed large deviations from the ideal case. The instrument was frequently returned to the NGS Instrumentation and Equipment Section in Corbin, Va., for adjustment. In general, the instrument was found to be in satisfactory adjustment when checked using NGS's two 1200-millimeter focal-length collimators. These

*The author of this report had substantially completed it by November 1981 when, due to serious illness, his working career ended.

collimators were acquired from Jenoptik and are used by NGS for the sole purpose of adjusting NI 002 leveling instruments to the manufacturer's specifications.

Even when collimation errors C_1 and C_2 were found to satisfy required tolerances during the laboratory test, field personnel still encountered problems with reading checks when unbalanced sight distances occurred during leveling. It was then suspected that either external or internal causes (or both) affected the adjustment of the instrument in an unknown manner. External effects appeared to be eliminated when shipping containers were redesigned and more effectively padded to cushion the instrument against rough handling during shipment. At Corbin, refined mechanical locking devices were installed inside the instrument to reduce undesirable vibration and abrupt movement of vital parts in the instrument to a negligible level.

Even after these improvements were made, field personnel had problems with apparent inconsistencies in the adjustment of the instrument. Part of the problem was traced to the procedure for determining collimation error (in particular, atmospheric refraction effects on the observations). It was found that when the necessary observations were made very early in the morning, i.e., during a time of positive temperature gradients, the results indicated the instrument was out of adjustment, while a second determination performed during prevailing negative temperature gradients (the air at ground level is warmer than the air 1-2 m above ground level) showed the instrument was in acceptable adjustment. NGS now requires its field personnel to determine collimation errors only during periods of negative temperature gradient.

Another part of the problem was discovered by chance when an operator inadvertently breathed on the invar bands of a compensator while an instrument was open for adjustment work. Breathing against the compensator caused the line of sight of the instrument to change significantly. Reviewing related literature led the author to conduct a series of tests to determine the behavior of the NI 002 compensator under the influence of temperatures changing both outside and inside the instrument.

On several occasions the manufacturer had indicated that the NI 002 was sensitive to changes in temperature, but that the introduction of the reversible-compensator concept greatly reduced the problem while still providing a quasi-absolute horizon.

EXPERIMENTS

To verify the manufacturer's claims and bolster NGS confidence in the capability of the NI 002, four independent tests were performed:

1. Long-term heating of the instrument from one side only.
2. Simulated C-determinations.
3. Simulated routine leveling in a latitudinal direction.
4. Simulated routine leveling in a meridional direction.

During the tests the instrument was positioned between the two Jenoptik collimators (fig. 1). They were aligned in such a way as to establish a horizontal plane which then served as a reference to monitor the positions of the line of sight during each of the tests. The observations had an

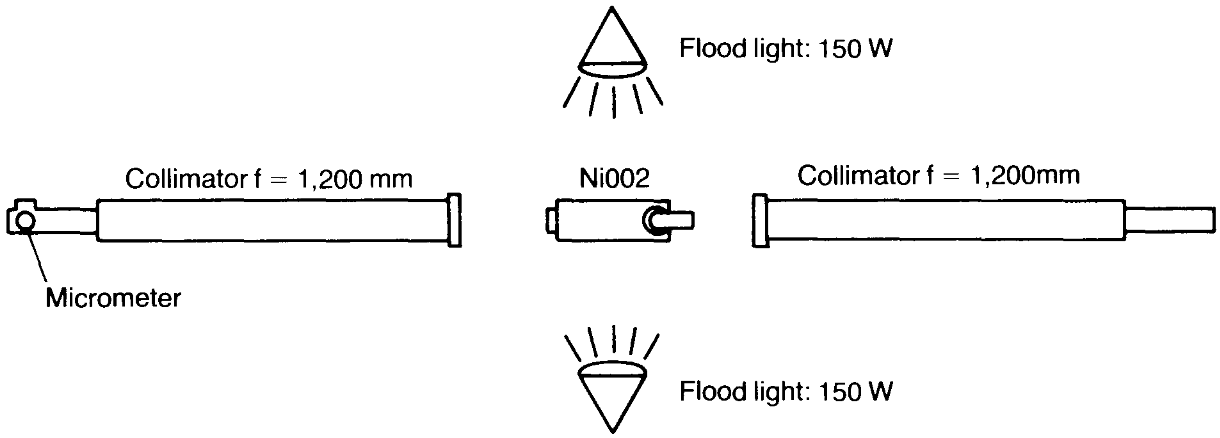

Figure 1.--Arrangement of equipment.

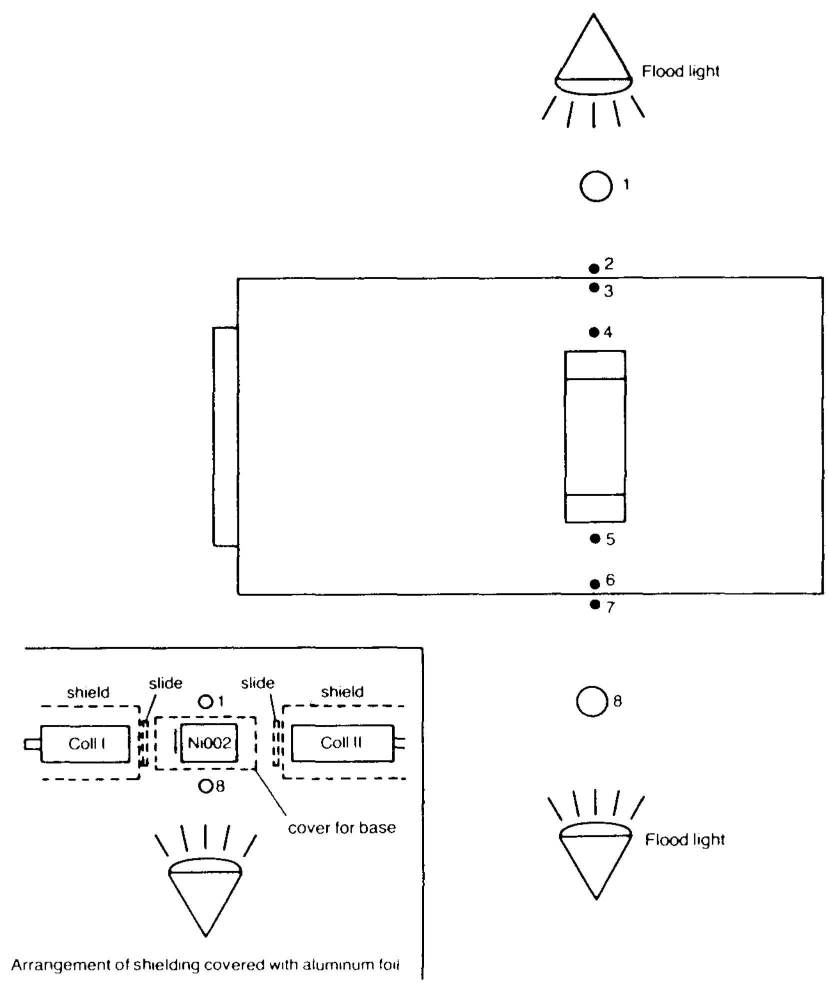

Figure 2.--Schematic of thermistor and heat lamp locations for tests 1, 2, and 3.

uncertainty of ±0.3 to ±0.5 arc seconds. To ensure stability during the testing, the collimators were shielded so they were not significantly affected by the heat sources used to warm the leveling instrument (fig. 2). Because an opening had to be cut in the shielding in front of the front lens of the collimators, a slide was moved to cover the opening whenever the position of the line of sight was not being observed. In addition, the stability of the collimators was monitored with striding levels from T-4 theodolites mounted on each of the collimators.

In test 1, the leveling instrument was heated by one 150-watt floodlight. In tests 2 and 3, two floodlights were positioned 0.3 m from either side of the instrument. In test 4, the floodlights were mounted overhead at an angle of about 45° and 0.3 m from the instrument (fig. 3).

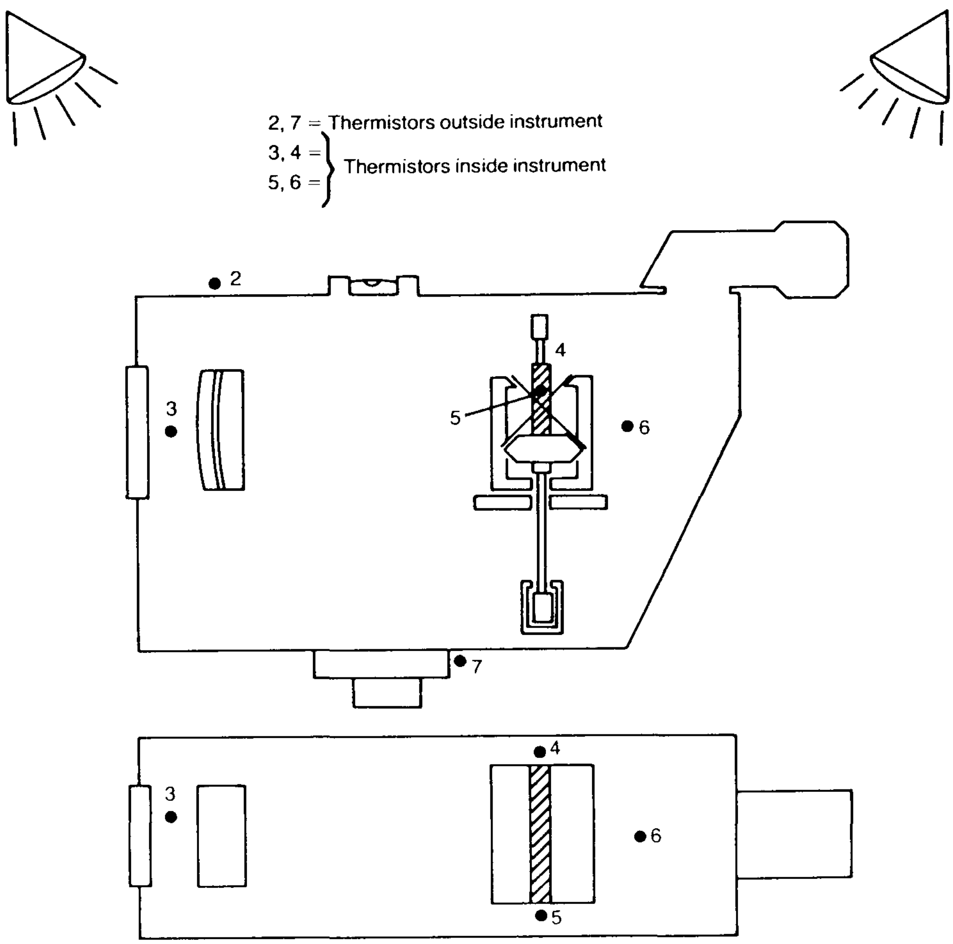

Figure 3.--Schematic showing location of thermistor and heat lamp during test 4.

An array of eight thermistors was used in test 1, four in tests 2 and 3, and six in test 4. The thermistors continuously monitored temperatures both outside and inside the instrument (with an uncertainty of ±0.2°C). The air temperatures outside the instrument were difficult to determine due to the direct exposure to the heat sources which caused rapid changes. Figures 2 and 3 show the locations of the thermistors.

Test 1

Prior to the heating phase, the two compensator positions were observed five times each and the temperatures at the eight thermistors recorded. After these initial readings, the floodlight was turned on. This light remained on until the temperature at the thermistor nearest the light reached its apparent maximum and stabilized at about +49°C. This took 210 minutes. (See fig. 4.) The light was then turned off. The temperatures at all thermistors immediately began decreasing and were monitored until the initial level was reached. The cooling phase lasted 110 minutes. (See fig. 5.) During the heating and cooling phases, compensator positions and temperatures were first monitored at 5-minute intervals. This time span was needed to read the collimator micrometer and the eight thermistor temperatures. After about 30 minutes, the rise in temperature slowed noticeably, and the observations were taken less frequently.

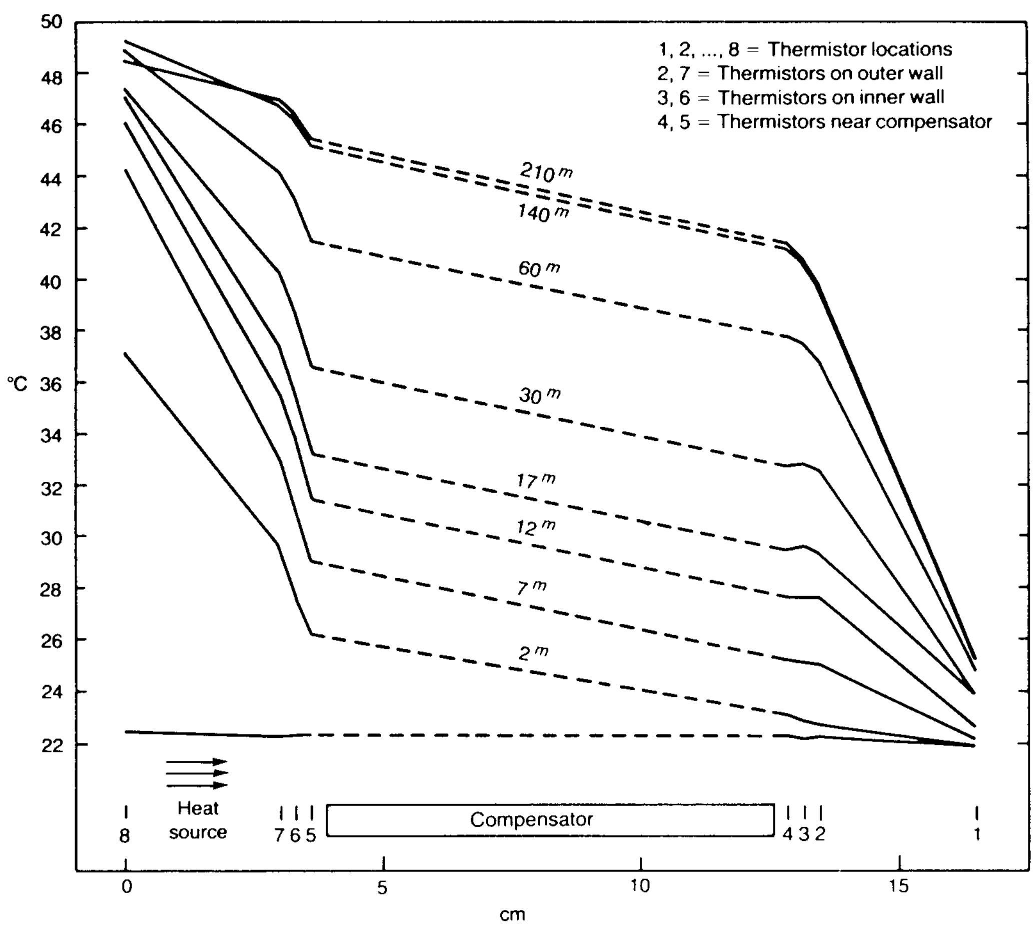

Figure 4.--Range of temperatures during heating phase, test 1.

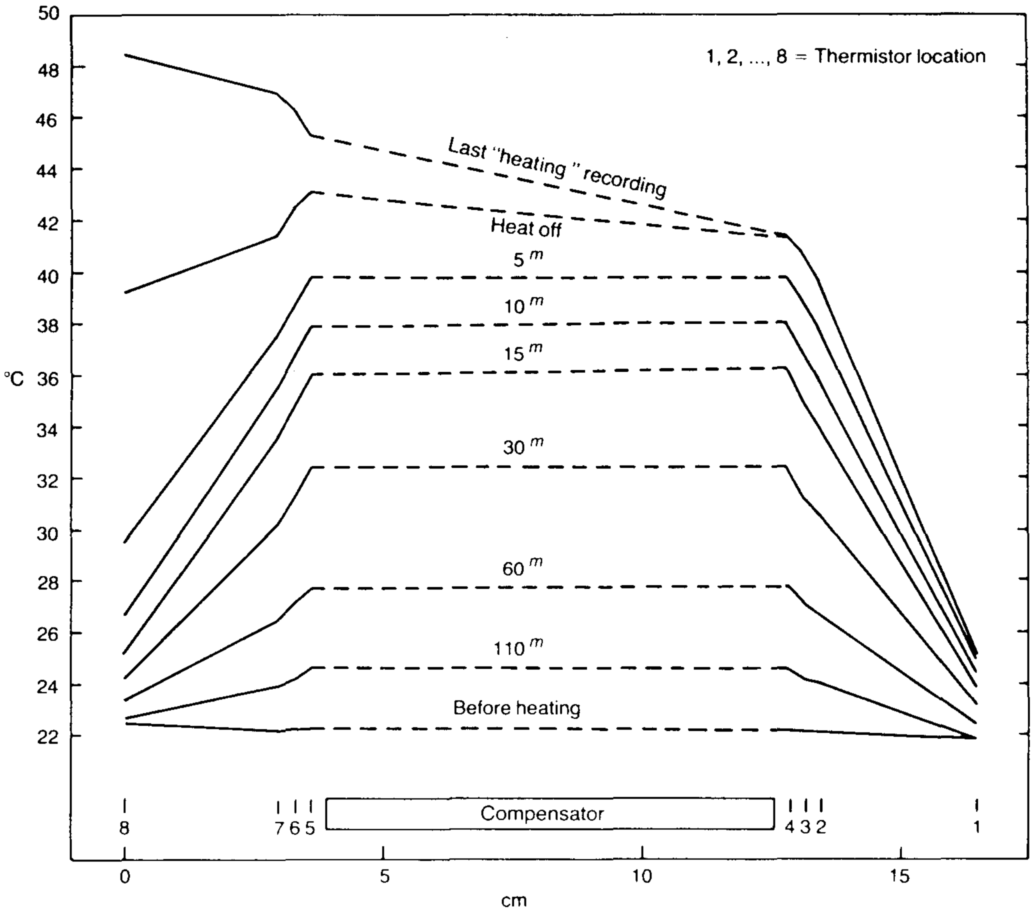

Figure 5.--Range of temperatures during cooling phase, test 1.

Tests 2, 3, and 4

In tests 2, 3, and 4, two identical floodlights were employed to simulate a standard leveling observation sequence, i.e., backward-forward-forward-backward (BFFB). (See figs. 2 and 3.) This procedure was necessary because the leveling instrument could not be rotated 180°. The restricted movement was caused by the wiring which connected the thermistors to the temperature meter.

The "heating" sequence was patterned in the following manner: First, light "A" was turned on for 30 seconds for the first "B-reading" with the compensator in position I. Then, "A" was turned off and light "B" turned on for the first "F-reading" with the compensator still in position I. After 30 seconds, the compensator was reversed (position II) for the second "F-reading." After another 30 seconds, light "B" was turned off and light "A" turned on again for another 30 seconds and the second "B-reading" simulated. An observation cycle of 2 minutes was simulated in this way. Another 2 minutes were allowed for "movement between setups." A total cycle time of 4 minutes was established, which is considered representative of average field conditions.

Since test 2 was designed to simulate the procedure for determining collimation errors C_1 and C_2 by using Kukkamaki's method, an additional heating sequence was applied to simulate the "off-balanced position," wherein the leveling instrument is set 20 m from the nearest leveling rod. After completion of the standard reading cycle, BFFB (described previously), the leveling instrument was heated from only one side for 2 minutes with the compensator in position I and for another 2 minutes with the compensator in position II. This accounted for the BFFB observations at the off-balanced setup in both compensator positions.

The position of the line of the sight was observed at the beginning, during, and end of each simulated test cycle. Temperatures were observed at four thermistors, i.e., one at either side of the compensator and one at either of the outside walls of the instrument during the individual B and F phases.

During test 3, which simulated routine leveling progressing in a latitudinal direction, the floodlights were pointed alternately onto the "broad" sides of the leveling instrument. In test 4, which simulated routine leveling progressing in a meridional direction, the floodlights were pointed alternately onto the front and rear of the instrument from above at an angle of about 45°.

RESULTS

The results obtained from all the tests clearly show that compensators in NI 002 leveling instruments respond to temperature changes depending on the length of the heating period. This causes a change in individual compensator positions I and II relative to each other and relative to their initial positions. Consequently, the positions of the individual lines of sight are also affected. Fortunately, the changes are, in general, symmetric about the grand mean of any one series of C-determinations obtained during the individual tests; therefore, the principle of the quasi-absolute horizon <u>is</u> maintained.

Test 1

In test 1, the instrument was heated from only one side for 210 minutes, at which time the temperature of thermistor 8 (closest to the heat source) stabilized at about +49°C. The heat source was then turned off and the cooling period lasted 110 minutes, at which time the temperature of thermistor 8 returned to its initial level. (See figs. 4 and 5.)

The positions of the individual lines of sight changed steadily, rapidly, and almost symmetrically during the first 90 minutes of the heating phase. During that time the temperature of thermistor 8 increased by about 26°C, while the temperatures of thermistors 4 and 5 (at the compensator) rose by 19°C and 23°C, respectively. This difference is explained by the fact that thermistor 5 was located nearer the heat source than thermistor 4. Even the temperature of thermistor 1, farthest from the heat source and shielded by the instrument, increased by more than 3°C. The overall room temperature changed by about 0.5°C.

The angles of the lines of sight with the quasi-absolute horizon changed by about +14.5 arc seconds during the heating period and stayed at about this level after the temperature stabilized at about +49°C. As soon as heating was discontinued, the two lines of sight returned steadily and rapidly to their original position within 110 minutes. (See fig. 6.) The slight

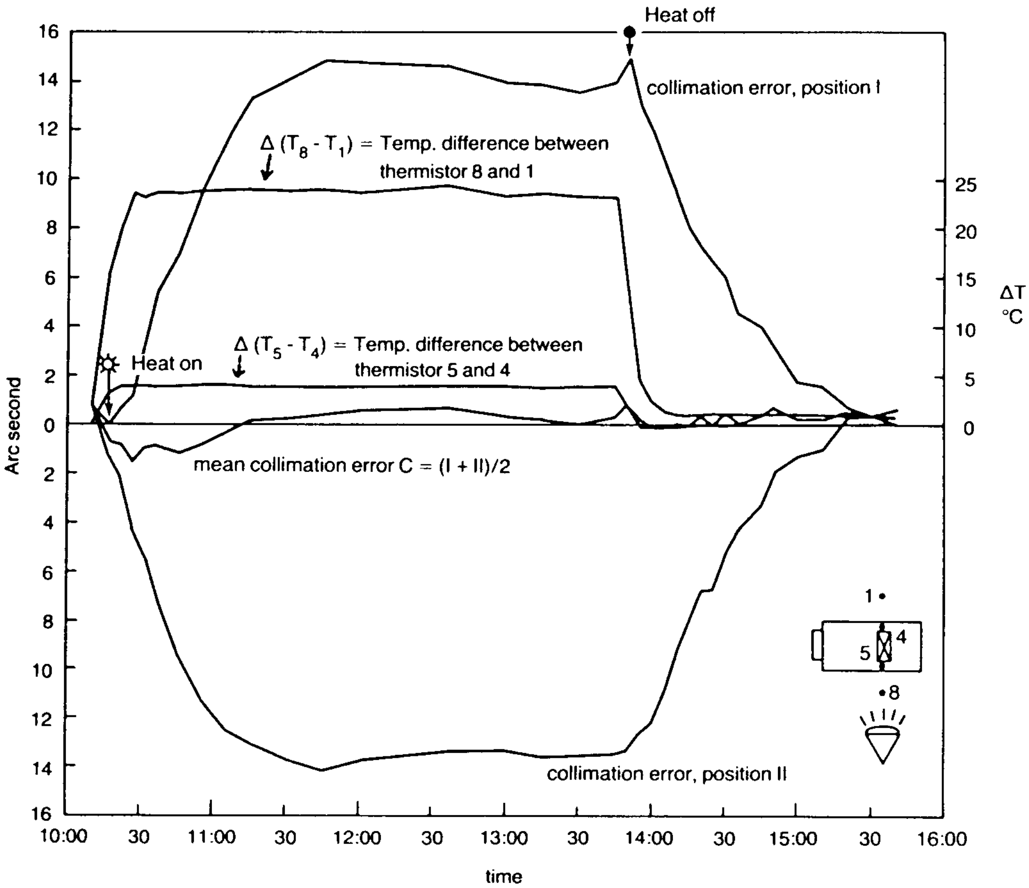

Figure 6.--Range of compensator positions I and II, and temperature differences between thermistors 1 and 8 and 4 and 5 during test 1.

irregularities in any otherwise symmetrical pattern of behavior of collimation errors may also be attributed to physical and observational problems. The correlation between the two collimation factors was r = -0.98, indicating the compensator was very well behaved during the test.

Test 2

The second test simulated the collimation error determination which is accomplished routinely by field personnel using Kukkamaki's method. Two floodlights were installed to heat each side of the leveling instrument alternately. The BFFB observation sequence was followed. Two series of collimation checks were observed. The first series consisted of three determinations and the second had two successive determinations. It is interesting to note that even during the short periods of heating, i.e., 30 and 60 seconds, respectively, not only did the temperatures at the outer walls of the instrument rise, but also those inside the instrument. The temperatures did not change uniformly; instead, they reflected the heating sequence as expected. Basically all thermistors recorded an increase in temperature, not only within a collimation check cycle, but also from cycle to cycle (with decreasing amounts). (See fig. 7.)

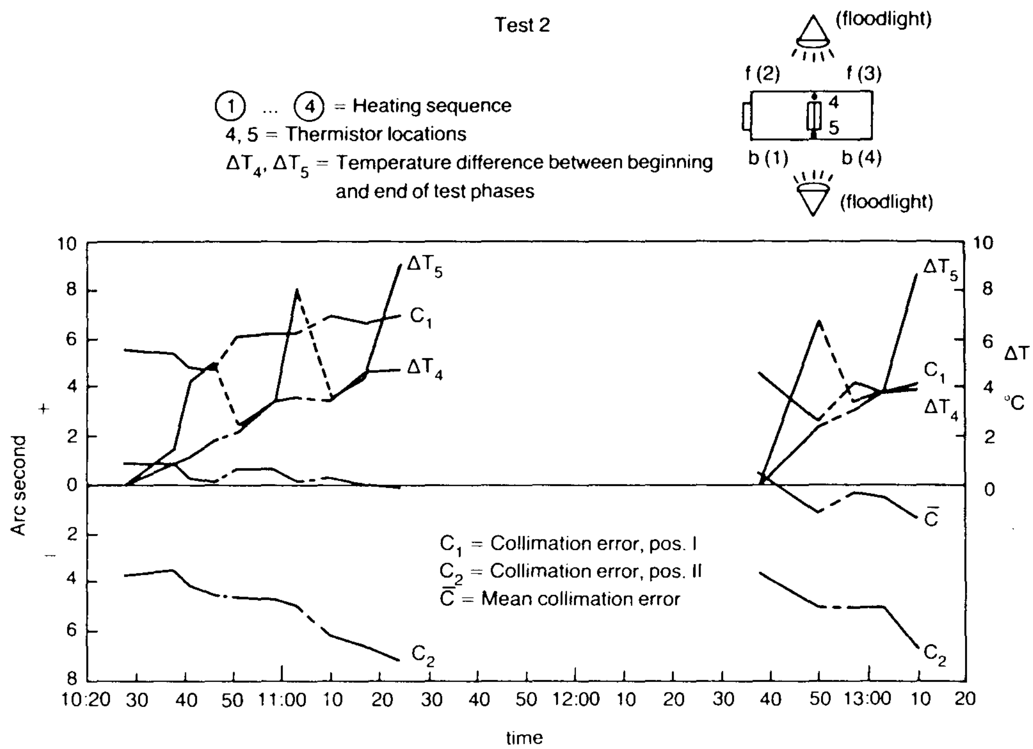

Figure 7.--Variations of collimation errors due to temperature change, test 2.

The collimation errors showed an irregular behavior which was anticipated due to the heating sequence in which a mix of alternating and one-sided heating was applied to simulate the observational procedure during a collimation check.

Lines of sight deviated by 0.2 to 1.2 arc seconds from their initial positions from the beginning to the end of the individual collimation check cycles. An obvious pattern which might indicate stabilization could not be determined with repeated observations.

Test 3

The third test was designed to simulate leveling that is proceeding in a latitudinal direction. The observing sequence was again BFFB, simulated by turning on the heat sources alternately. Five "sections," consisting of 10 "setups" each, were "observed." The temperature again showed a steep increase in the beginning, as in test 1, with a rise of about 9°C over 40 minutes, followed by a drop of about 2°C before the next "section" was "observed." In the next section the temperature rose again by 2 to 3°C in about 40 minutes. During an interruption of 1 hour the temperatures returned to within 2°C of their original values. When the next three sections were observed, the temperatures increased and decreased during and between sections in much the same way as they did during the first two sections. This provided evidence that temperature variation "tapers off" and stays within a certain range. (See figs. 8 and 9.) In test 4 as well, the two thermistors (4 and 5) on the sides of the compensator recorded temperatures which differed very little. (The irregularities in "setups" 5 and 6 were caused by a faulty heating sequence.)

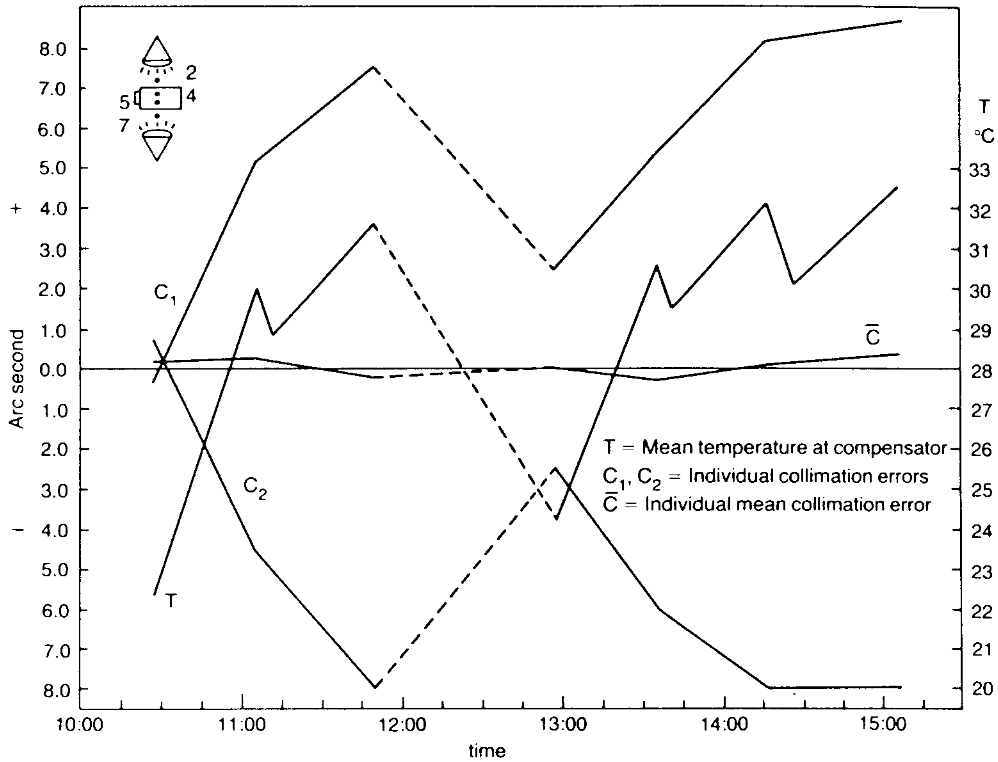

Figure 8.--Collimation error and mean temperature at compensator, test 3.

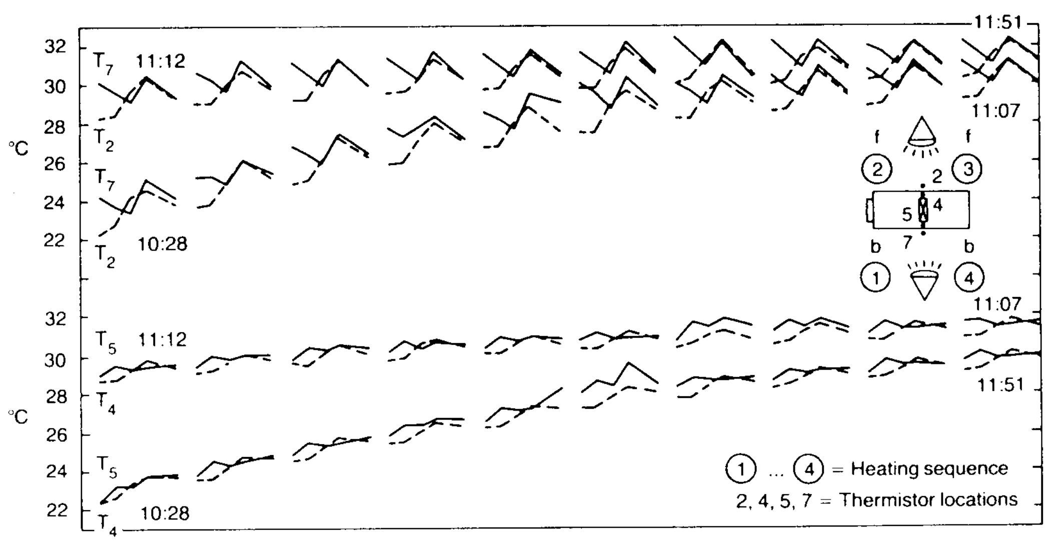

Figure 9.--Range of temperatures at thermistors 4 and 5 (near compensator) and thermistors 2 and 7 (on outside walls of instrument) during two consecutive sections, test 3.

The lines of sight changed rapidly in the beginning of the observation cycle, and during the break of 1 hour, when drastic temperature changes occurred. The minor temperature changes between sections apparently did not significantly affect the lines of sight, i.e., the collimation errors. It appeared as if the collimation errors stabilized, reacting (with delay) to the temperature stabilization. The changes of the magnitude of the individual collimation errors were nearly symmetric about their mean.

Test 4

In the fourth test (fig. 10), involving routine leveling progressing in a meridional direction, the heat sources were relocated so that the front and rear of the leveling instrument were heated alternately in accordance with the standard observation procedure. (Also see fig. 3.) The thermistors were also rearranged, except for the two thermistors on the sides of the compensator. One was placed between the compensator and the rear wall of the instrument (6), one on top over the lens (2), and one underneath the instrument close to the vertical axis (7). (Thermistors 2 and 7 are not visible in illustration.)

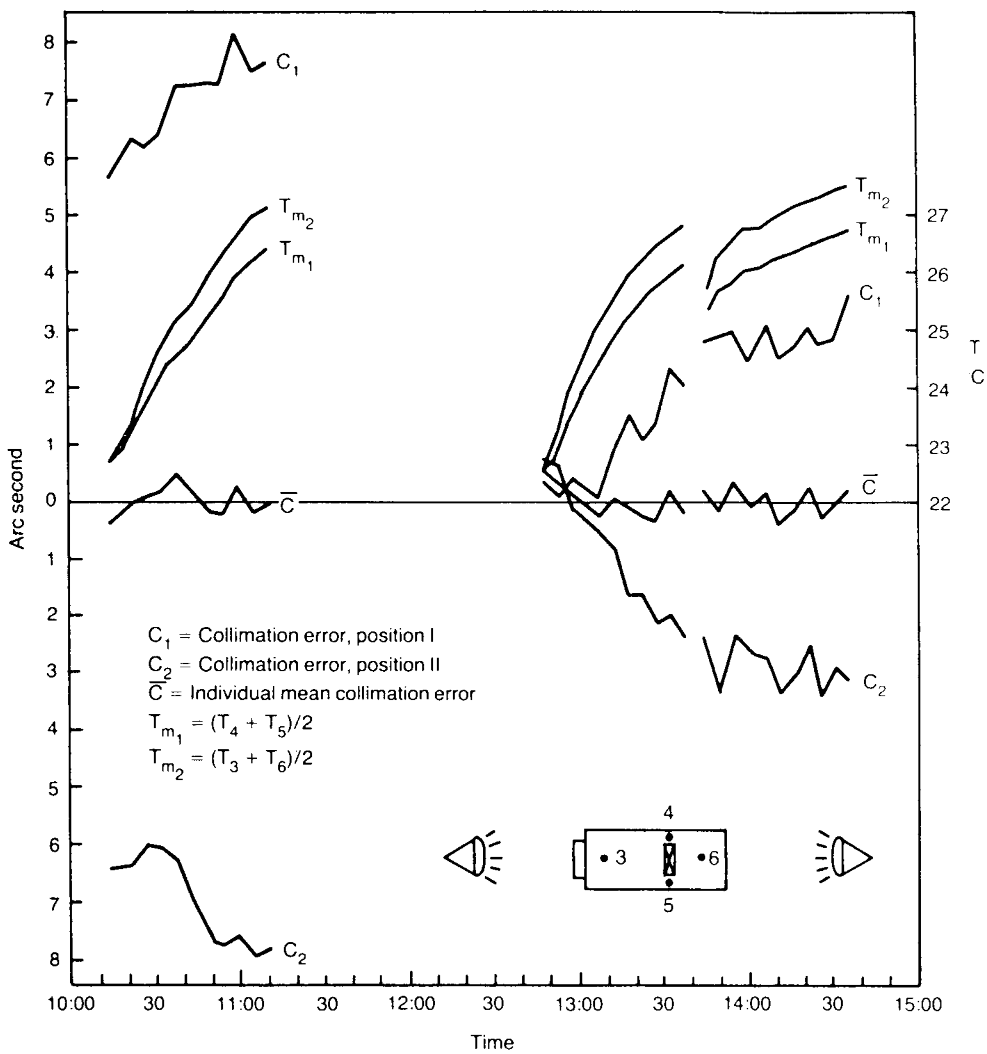

Figure 10.--Range of compensator positions I and II and mean temperature at compensator and between interior far ends, test 4.

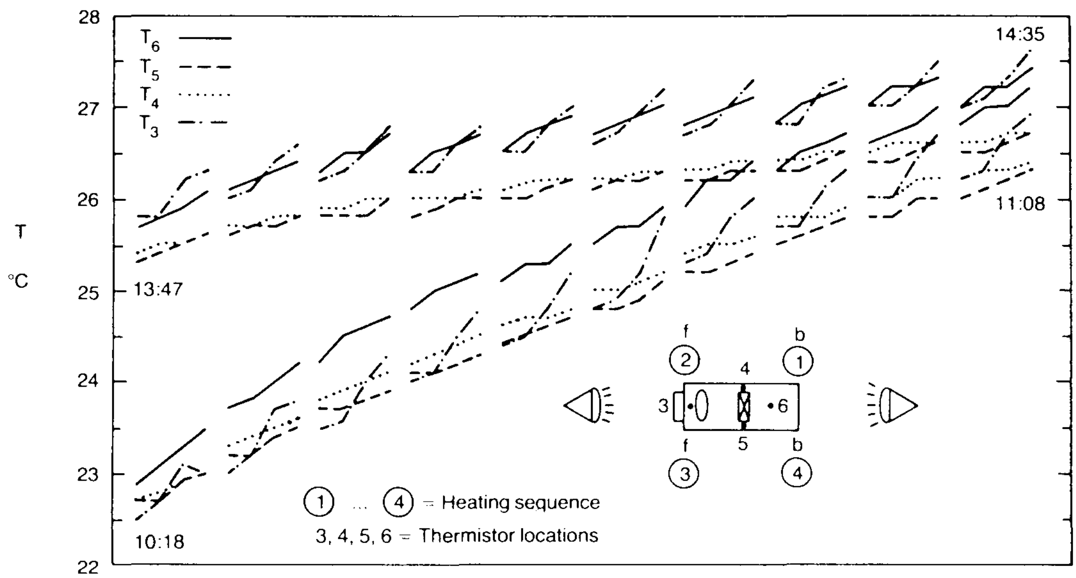

Figure 11.--Range of temperature at thermistors 3 and 6 (near front and rear ends, inside instrument) and thermistors 4 and 5 (either side of compensator during two sections, test 4.)

Three "sections" with 10 "setups" each were observed. As expected, the temperature at (7) increased the least, about 3.5^{o}C during the first "section."

In figure 11, the trend of the temperatures at the two thermistors on the sides of the compensators, and thermistors (3) and (6) has been plotted for the first and the third sections. The plot shows that the temperature rise in the first section is considerably more pronounced than in section 3. The temperature differences of the two pairs of thermistors under consideration (3, 6 and 4, 5) became smaller with time, which was especially obvious with thermistors 3 and 6. The temperature seemed to stabilize over time, as discussed previously. The behavior of the temperatures indicates that the air mass within the instrument does not heat uniformly. This is probably caused by structural parts that obstruct the free flow of air. "Hot" spots seemed to develop. It is interesting to note that in the beginning the temperature at (3) near the front lens always stayed cooler than at (6) in the rear. In the third section, thermistors (3) and (6) recorded almost the same temperature. Section 2 was observed after a break of 90 minutes which was needed to readjust the instrument. The same trend as in "section" 1 was observed in the range of temperatures, with almost identical temperatures at the various thermistors. The compensator responded to the temperature changes in a similar manner as in the preceding test. The deviations of the individual collimation errors from the grand mean showed the same characteristics, despite the fact that the compensator had been readjusted between sections 1 and 2.

CONCLUSION

The compensator of the NI 002 leveling instrument performs very well and maintains the principle of the quasi-absolute horizon as stated by the manufacturer. The tests have shown that the NI 002 responds to temperature changes and, therefore, the two lines of sight created by the two pendulum positions also change. However, the changes occur in a very symmetric fashion and are not harmful.

An important conclusion must be kept in mind. The changing lines of sight, and with these the values of collimation errors, cause a change in the q-factor (the q-factor is the difference of the two collimation errors and is applied to facilitate a reading check when unbalanced sight distances are used in leveling). From the test results it is obvious that the usefulness of the q-factor becomes questionable as soon as the atmospheric conditions which existed at the time of the collimation check change. Since the q-factor only serves to establish a reading check, it should probably be abandoned and another reading check introduced by which low-scale and high-scale elevation differences may differ depending on the amount of unbalance. The functioning and adjustment of the compensator should be monitored by inspecting the size and sign of both the mean and the difference of the individual collimation errors.

These tests were performed under laboratory conditions and cannot be considered entirely representative of actual field work. Additional problems may occur when leveling progresses along partially shaded locations or over varying ground cover. Unstable weather conditions may also cause unpredictable situations. However, the short response time of the compensator to thermal changes seems to aid in obtaining acceptable results.

It seems reasonable to assume that other compensator instruments will react to heating in a similar way. Therefore, the position of the line of sight would change. Since instruments other than the NI 002 do not provide a quasi-absolute horizon, it is not possible to account for the deviation of the line of sight from the one determined for that day. The use of balanced sight distances then becomes mandatory so that the effect of collimation error is minimized. This is not absolutely necessary when working with the NI 002.

ACKNOWLEDGMENT

The author would like to recognize the cooperation provided by Messrs. Jerry Pryor and Edward Swift of the NGS Instrumentation and Equipment Section.

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